VU Research Portal

Using network reification for adaptive networks

Treur, Jan

published in
Network-Oriented Modeling for Adaptive Networks: Designing Higher-Order Adaptive Biological, Mental and Social Network Models
2020

DOI (link to publisher)
10.1007/978-3-030-31445-3_16

document version
Publisher's PDF, also known as Version of record

document license
Article 25fa Dutch Copyright Act

Link to publication in VU Research Portal

citation for published version (APA)
Treur, J. (2020). Using network reification for adaptive networks: Discussion. In J. Treur (Ed.), *Network-Oriented Modeling for Adaptive Networks: Designing Higher-Order Adaptive Biological, Mental and Social Network Models* (pp. 405-412). (Studies in Systems, Decision and Control; Vol. 251). Springer International Publishing AG. https://doi.org/10.1007/978-3-030-31445-3_16

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:
vuresearchportal.ub@vu.nl

Download date: 05. May. 2023

Chapter 16
Using Network Reification for Adaptive Networks: Discussion

Abstract In this final chapter, the most important or most remarkable themes recurring at different places in this book are briefly summarized and reviewed. Subsequently the following themes are addressed: (1) How network reification can be used to model adaptive networks. (2) The formats in which conceptual representations of reified networks are expressed graphically using 3D pictures and role matrices. (3) The universal combination function, and the universal difference and differential equation as the basis for the numerical representation and implementation of reified networks. (4) Analysis of how emerging reified network behaviour relates to the reified network's structure. (5) The Network-Oriented design process based on reified networks. (6) The relation to longstanding themes in AI and beyond.

16.1 Adaptive Networks and Network Reification

This theme is a major theme throughout the whole book. It started in Chap. 1, Sects. 1.2 and 1.3 with an overview of many types of adaptive networks and domains in which adaptation of the network structure plays an important role. As adaptation principles can themselves also be adaptive, it is natural to consider adaptive networks of different orders. As described in Chap. 1, Sect. 1.3, it was found out that in the literature first-order adaptation occurs often, but second-order adaptation much less and third- or higher-order adaptation is almost absent. Modeling adaptive networks is usually done in a hybrid format: the network itself is described by some form of network modeling, but the adaptation principles are described using some form of procedural or algorithmic specification and programming to run the underlying difference equations. Thus a hybrid model consists of two components for two different types of models that interact with each other, as depicted in Chap. 1, Fig. 1.2.

In contrast to this hybrid approach, in Chap. 3 it was shown how network reification for temporal-causal networks can be used to model any adaptive network in a neat and declarative manner from a Network-Oriented Modeling perspective,

© Springer Nature Switzerland AG 2020

J. Treur, *Network-Oriented Modeling for Adaptive Networks: Designing Higher-Order Adaptive Biological, Mental and Social Network Models*, Studies in Systems, Decision and Control 251, https://doi.org/10.1007/978-3-030-31445-3_16

where also the adaptation principles are described in temporal-causal network format. Chapter 3 shows several examples of this for well-known first-order network adaptation principles, for example, shown in Figs. 3.4 to 3.10. In Chap. 4, second-order adaptive networks were addressed with an example (shown in Fig. 4.3) for plasticity and metaplasticity as considered in relatively recent empirical literature from the Cognitive Neuroscience domain.

Concerning the challenge of obtaining plausible adaptive network models of order >2, in Chaps. 7 and 8 three of such examples were presented. In Chap. 7 an example of such a reified adaptive network of order >2 was put forward that was inspired by literature on evolutionary processes (Fessler et al. 2005, 2015; Fleischman and Fessler 2011) as discussed in Chap. 1, Sect. 1.3. In Chap. 8, another example of a reified adaptive network of order >2 was described, this time inspired by Hofstadter (1979, 2007)'s ideas about Strange Loops; see also Sect. 16.6 below, and Fig. 16.3.

In the many examples in this book it was shown how a certain adaptation principle known from the literature can be formulated easily in reified temporal-causal network format. That this is possible, is not a coincidence, as in (Treur 2017) it was proven that any (state-determined) dynamical system as considered by Ashby (1960), Port and van Gelder (1995) can be modeled in temporal-causal network format. So, this gives confidence that in principle any hybrid adaptive network model can as well be (re)modelled as a reified temporal-causal network model.

It was shown by the many examples that the Network-Oriented Modeling approach based on network reification offers a huge potential for modeling quite complex adaptive network behaviour of any order. To execute such reified network models, it was shown in Chap. 9 that due to the unified approach for all levels of reification, quite compact software can be developed.

16.2 Conceptual Representations of Reified Networks: 3D Pictures and Role Matrices

Designing and presenting reified network models in a conceptually transparent manner comes with some minor challenges concerning structuring of pictures and data involved. For graphical conceptual representations of reified network structure pictures, this minor issue was resolved by using pictures that are literally transparent and are depicted in a 3D form with horizontal planes above each other for the base level and the reification levels, as shown in Fig. 16.1. Many pictures like this can be found in the book; e.g., Chap. 3, Figs. 3.4–3.10; Chap. 4, Fig. 4.3. This is in contrast to the flat 2D style of depicting networks, for example, in (Treur 2016) and many papers.

This 3D picture style has become a kind of standard now for these reified networks and can be found everywhere in the current book.

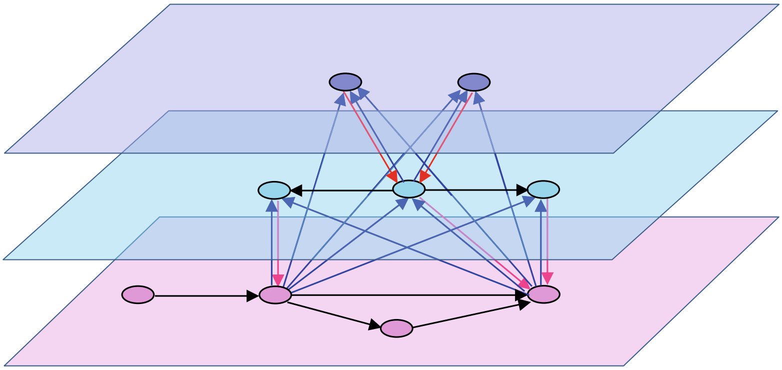

Fig. 16.1 The 3D style of graphical conceptual representations for reified networks

The other minor challenge of representing the relevant data was resolved by the choice for a specific table format to represent separately in a grouped form the different types or roles of these data (base connectivity, connection weights, speed factors, combination function weights, and combination function parameters) that define a specific reified network model: a separate role matrix for each of the roles played by these data. Also this format can be found at many places in the book (e.g., Chap. 2, Sect. 2.4, Box 2.1; Chap. 3, Sect. 3.7.2, Box 3.8; Chap. 4, Sect. 4.4.2, Box 4.1) and has now become a kind of standard. The modeling environment that was implemented makes use of this role matrix format as input (see Chap. 9, Sects. 9.2 and 9.4).

16.3 The Universal Combination Function and the Universal Difference and Differential Equation

Another remarkable theme that has occurred several times in the book concerns the universal combination function that was found for reified networks, and the universal difference and differential equation. For the non-reified case, in Chap. 2, Sect. 2.3.1 it was discussed how each state has its own combination function and basic difference and differential equation. These are specific for each state due to the specific values of the elements such as connection weights, speed factors, and combination function weights and parameters as specified in the role matrices. Given values for all these elements as specified in the role matrices, for each state its specific combination function and difference and differential equation can be derived in a standard manner as shown in Chap. 2, Sect. 2.4.2, Box 2.2

However, if a network is fully reified, there are not such static values for each base state, as they have become variables linked to their reification states.

The remarkable thing is that what remains is one single universal format for the combination function and also for the difference and differential equations that are used for every state at the base level and at any reification level; see Chap. 3, Sect. 3.5, and Chap. 4, Sect. 4.3.2. This enables a unified approach for a computational reified network engine implementation that handles all reification levels in a uniform manner. This provides powerful means to model very complex adaptive network behaviour, which can be adaptive of any order, in a relatively easy manner. And also due to this, the universal difference equation is the basis for the remarkably compact implementation described in Chap. 9, Sect. 9.4.

In Chap. 10 a more in depth treatment of the universal combination function and universal difference and differential equation is offered. For example, in Sect. 10.4, Box 10.4 it is shown how they can be derived. In Sect. 10.7 it is shown how the universal differential equation can be used for a compilation process that leads to the specification of a set of differential equations that can be run efficiently by any general purpose differential equation solver. This would be an alternative type of implementation, probably useful for large scale reified networks; this still has to be implemented and tested.

16.4 Analysis of How Emerging Reified Network Behaviour Relates to the Reified Network's Structure

The interesting theme how emerging network behaviour relates to network structure also occurs extensively in the book. The picture in Fig. 16.2 (also used in some other chapters) indicates the different relations for this theme.

The network structure is what is specified in the role matrices. The arrow at the bottom layer was addressed in more detail in Chap. 10, Sect. 10.6, Box 10.6 where it is shown how from the role matrices for the network structure characteristics the numerical representation in the form of the difference and differential equations can be derived that describes the network's dynamics. In Chap. 3, Sect. 3.7.4, and many examples in Sect. 3.6 it is shown how a reified network's emerging behaviour depends on the reified network's structure characteristics such as parameters of

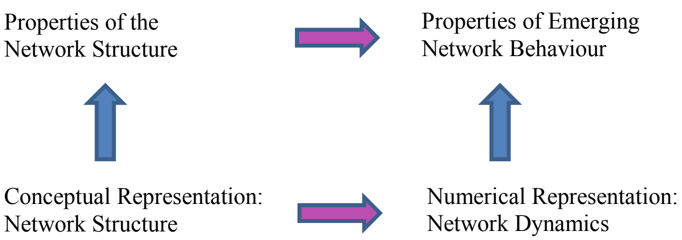

Fig. 16.2 Bottom layer: the conceptual representation defines the numerical representation. Top layer: properties of network structure entail properties of emerging network behaviour

combination functions. Similarly, in Chap. 5, Sect. 5.6; Chap. 6, Sect. 6.6, and Chap. 7, Sect. 7.5 this is shown for other example reified networks. All these deal with specific network models and relate to the bottom layer in Fig. 16.2.

However, in Chaps. 11 to 14 the step is made to the upper layer in Fig. 16.2. In these cases not specific network structures are considered, but classes of networks that satisfy certain network structure properties concerning connectivity and aggregation in terms of combination functions. In Chaps. 11 and 12 this is addressed for non-reified networks, leading to a number of results of the form that a certain set of network structure properties entails certain properties concerning the network's emerging behaviour, for example, that all states eventually get the same value. Similar analysis methods have been applied to reification states in Chaps. 13 and 14, in particular for adaptive bonding by homophily and for Hebbian learning, respectively. In this way in Chap. 13 results were found on how properties of reified network structure characteristics entail properties of community formation. In Chap. 14 results were found, for example, on how certain properties of combination functions for Hebbian learning entail the maximal final values of the connection weights.

Given that it is sometimes argued that emerging behaviour in general cannot be derived from the structure of a model, it might be felt as a surprise that this turns out not to be true for quite a number of cases, also nonlinear ones, as still many positive results have been found on the relation between network structure and network behaviour. All such results can be used for verification of network models. If in a simulation, behaviour is observed that contradicts one of these results, the network's implementation has to be inspected and improved.

16.5 The Network-Oriented Design Process Based on Reified Networks

The Network-Oriented Modeling approach for adaptive networks based on network reification supports the modeller in a number of ways. Design of a model takes place based on declarative building blocks concerning the network's structure such as the network's connectivity and the network's aggregation based on a choice of combination functions. As a network's behaviour is fully determined by the network's structure, also dynamics and (multi-order) adaptation of the designed network is specified in such declarative terms. The specification format based on role matrices that is used is declarative, implementation-independent and compact but detailed.

More specifically, the basic elements of the role matrices format are declarative: connection weights, combination functions, speed factors, and role matrices grouping them are declarative mathematical objects. Together these elements determine in a standard manner first-order difference or differential equations, which are declarative temporal specifications; for example, see Chap. 3, Sect. 3.5, and Chap. 4, Sect. 4.3.2; Chap. 9, Sect. 9.4; Chap. 10, Sect. 10.4. Indeed, a reified network model's behavior is fully determined by these declarative specifications, given some initial values. The modeling process is strongly supported by using such declarative building blocks: very complex (multi-order) adaptive patterns can be modeled easily, and in (temporal) declarative form. All procedural details are taken care of by the developed software environment, as described in Chap. 9, and hidden for the modeler. The generic setup of the combination function library makes it easy to add new combination functions that are automatically incorporated as soon as they have been added to the library; see Chap. 9, Sect. 9.3. The modeling approach also comes with simple means for mathematical analysis and background knowledge on the relation between a network's structure and the network's behaviour by which reified network models can be verified on correctness; see Chap. 3, Sects. 3.6 and 3.7.4; Chap. 5, Sect. 5.6; Chap. 6, Sect. 6.6; Chap. 7, Sect. 7.5, and Chaps. 11–14.

16.6 Relations to Longstanding Themes in AI and Beyond

The modeling approach presented in this book allows declarative modeling of dynamic and adaptive behaviour of multiple orders of adaptation. Traditionally declarative modeling approaches are a strong focus of AI. There are two longstanding themes in AI to which the work presented in this book contributes in particular: causal modeling (Kuipers 1984; Kuipers and Kassirer 1983; Pearl 2000) and metalevel architectures and metaprogramming (Bowen and Kowalski 1982; Demers and Malenfant 1995; Sterling and Beer 1989; Sterling and Shapiro 1996; Weyhrauch 1980). A main contribution to the causal modeling area is that this area is extended with dynamics and adaptivity of the causal modeling, not only addressing dynamics of the causal effects but also adaptive dynamics of the causal relations themselves. Without these extensions (multi-order) adaptive processes would be out of reach of causal modeling. A main contribution to the area of metalevel architectures and metaprogramming is that now network models are covered as well while traditionally the focus in this area is mainly on logical, functional and object-oriented modeling or programming approaches. The concepts of this area indeed show their value for Network-Oriented Modeling based on reified networks.

Also some areas outside AI are worth mentioning. One of them is the area of Cognitive (Neuro)Science and Philosophy of Mind (Kim 1996, 1998) where it is described how mental states function based on the causal networks they form; see Chap. 2, Sect. 2.2.1. The approach offered in this book applied in particular to Mental Networks can be considered as contributing to further formalisation and operationalisation of such perspectives. Also the more theoretical analysis of Hebbian learning (Hebb 1949) in Chap. 14 contributes to Cognitive (Neuro) Science.

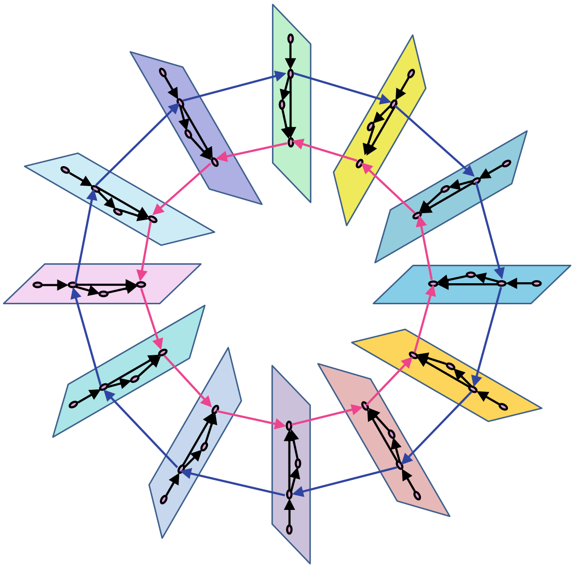

Fig. 16.3 Reified network model with cyclic reification level structure modeling Hofstadter (1979, 2007)'s Strange Loop

Another contribution to Philosophy of Mind and Cognitive (Neuro)Science is found in Chap. 8, where philosopher Hofstadter (1979, 2007)'s idea of Strange Loops as crucial element for human intelligence and consciousness is modeled by a three examples reified network with a cyclic reification level structure of the kind as summarized in Fig. 16.3 (for a bigger picture, see Chap. 8, Sect. 8.3, Fig. 8.5).

Another area with a long tradition worth mentioning is the area of Social Networks (e.g., Moreno 1934; Luce and Perry 1949; Leavitt 1951; Bott 1957; Banks and Carley 1996). The approach to Network-Oriented Modeling based on network reification provides a more principled approach to (multi-order) adaptive Social Networks than the often used hybrid approach; see Chap. 1, Sect. 1.4. Moreover, the more theoretical analyses of emerging behavioural patterns for social contagion in Chaps. 11 and 12 and for bonding based on homophily in Chap. 13 also particularly contribute to the area of Social Networks.

References

Ashby, W.R.: Design for a Brain. Chapman and Hall, London (second extended edition). First edition, 1952 (1960)

Banks, D.L., Carley, K.M.: Models for network evolution. J. Math. Sociol. **21**, 173–196 (1996)

Bott, E.: Family and Social Network: Roles, Norms and External Relationships in Ordinary Urban Families London, Tavistock Publications (1957)

Bowen, K.A., Kowalski, R.: Amalgamating language and meta-language in logic programming. In: Clark, K., Tarnlund, S. (eds.) Logic Programming, pp. 153–172. Academic Press, New York (1982)

Demers, F.N., Malenfant, J.: Reflection in logic, functional and object-oriented programming: a short comparative study. In: IJCAI'95 Workshop on Reflection and Meta-Level Architecture and their Application in AI, pp. 29–38 (1995)

Fessler, D.M.T., Clark, J.A., Clint, E.K.: Evolutionary psychology and evolutionary anthropology. In: Buss, D.M. (ed.) The Handbook of Evolutionary Psychology, pp. 1029–1046. Wiley and Sons (2015)

Fessler, D.M.T., Eng, S.J., Navarrete, C.D.: Elevated disgust sensitivity in the first trimester of pregnancy: evidence supporting the compensatory prophylaxis hypothesis. Evol. Hum. Behav. **26**(4), 344–351 (2005)

Fleischman, D.S., Fessler, D.M.T.: Progesterone's effects on the psychology of disease avoidance: support for the compensatory behavioral prophylaxis hypothesis. Horm. Behav. **59**(2), 271–275 (2011)

Hebb, D.O.: The Organization of Behavior: A Neuropsychological Theory (1949)

Hofstadter, D.R.: Gödel, Escher, Bach. Basic Books, New York (1979)

Hofstadter, D.R.: I Am a Strange Loop. Basic Books, New York (2007)

Kim, J.: Philosophy of Mind. Westview Press (1996)

Kim, J.: Mind in a Physical World: An Essay on the Mind-Body Problem and Mental Causation, MIT Press, Cambridge (1998)

Kuipers, B.J.: Commonsense reasoning about causality: Deriving behavior from structure, vol. 24. pp. 169–203, Artificial Intelligence (1984)

Kuipers, B.J., Kassirer, J.P.: How to discover a knowledge representation for causal reasoning by studying an expert physician. In: Proceedings of the Eighth International Joint Conference on Artificial Intelligence, IJCAI'83, pp. 49–56. William Kaufman, Los Altos, CA (1983)

Luce, R.D., Perry, A.: A method of matrix analysis of group structure. Psychometrika **14**, 95 (1949)

Leavitt, H.: Some effects of certain communication patterns on group performance. J. Abnorm. Soc. Psychol. **46**, 38 (1951)

Moreno, J.L.: Who Shall Survive? Nervous and Mental Disease. Publishing Company, Washington, DC (1934)

Pearl, J.: Causality. Cambridge University Press (2000)

Port, R.F., van Gelder, T.: Mind as motion: Explorations in the dynamics of cognition. MIT Press, Cambridge, MA (1995)

Sterling, L., Shapiro, E.: The Art of Prolog. MIT Press (Ch 17, pp. 319–356) (1996)

Sterling, L., Beer, R.: Metainterpreters for expert system construction. J. Log. Program. **6**, 163–178 (1989)

Treur, J.: Network-Oriented Modeling: Addressing Complexity of Cognitive, Affective and Social Interactions. Springer Publishers (2016)

Treur, J.: On the applicability of network-oriented modeling based on temporal-causal networks: why network models do not just model networks. J. Inf. Telecommun. **1**(1), 23–40 (2017)

Weyhrauch, R.W.: Prolegomena to a theory of mechanized formal reasoning. Artif. Intell. **13**, 133–170 (1980)